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THESIS

IMPROVING INTELLIGENCE, TARGETING, AND FIRE SUPPORT ALLOCATION FUNCTIONS IN THE FORCE EVALUATION MODEL (FORCEM)

by

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The Force Evaluation Model (FORCEM) is a low resolution, deterministic, time stepped combat simulation designed for the evaluation of force structures in a theater of operations. The fire support allocation module in FORCEM allocates battalions and type and quantity of ammunition to engage enemy targets based on input from experienced personnel. All enemy targets within an arbitrarily determined range of the CORPS or higher headquarters are considered for fire support engagement. In this thesis we propose a realistic method for determining field artillery targets to be considered eligible for engagement. We also formulate a linear programming problem to optimally allocate battalions and type and quantity of ammunition to the eligible targets. The results from the LP model compare favorably with those provided by FORCEM's fire support allocation module.

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Improving Intelligence, Targeting, and Fire Support Allocation Functions in the Force Evaluation Model (FORCEM)

by

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ABSTRACT

The Force Evaluation Model (FORCEM) is a low resolution, deterministic, time stepped combat simulation designed for the evaluation of force structures in a theater of operations. The fire support allocation module in FORCEM allocates battalions and type and quantity of ammunition to engage enemy targets based on input from experienced personnel. All enemy targets within an arbitrarily determined range of the CORPS or higher headquarters are considered for fire support engagement. In this thesis we propose a realistic method for determining field artillery targets to be considered eligible for engagement. We also formulate a linear programming problem to optimally allocate battalions and type and quantity of ammunition to the eligible targets. The results from the LP model compare favorably with those provided by FORCEM's fire support allocation module.

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I. INTRODUCTION

A. GENERAL

The Force Evaluation Model (FORCEM) is a low resolution, deterministic, time stepped simulation of air and ground combat in a theater of operations. The model was developed by the US Army Concepts Analysis Agency (CAA) to support force-level studies performed for Headquarters, Department of the Army. These studies provide analyses of theater force capabilities and sustainability requirements, both for U.S. and Allied Forces. The results from FORCEM provide insights to how changes in force structure, force capability, and logistics activities affect the outcome of a battle in a theater of operations. These changes are often a consequence of Congressional action, new equipment and tactics, and proposals at arms control talks. Traditionally, FORCEM is used extensively to model the European Theater of Operations. [Refs. 1: pp.3-4]

At the present time CAA is undertaking a major effort to improve the realism of FORCEM, particularly in the area of intelligence and target acquisition and allocation of firing units to the acquired targets.

The current methodology for intelligence and target acquisition is unrealistic in that all targets within a certain perception range of a Command and Control Headquarters (CAC) are assumed to be acquired for engagement by that CAC. This assumption ignores the fact that the CAC may not have a sensor capable of detecting the target. Moreover, the target may not have been conducting any operations that would be detectable by any of the CAC's sensors. To improve upon the methodology, CAA is in the process of introducing the use of detection probability into FORCEM. To augment this effort, we consider the problem of acquiring field artillery battalions as targets. This problem is much simpler than the problem of acquiring other types of targets. However, the acquisition method proposed herein can also be extended to other types of targets as well.

As for the allocation of the firing units, FORCEM currently assigns firing units to targets based on unrealistic assumptions concerning target prioritization, ammunition accountability, and firing unit selection rules. To eliminate these unrealistic assumptions, we formulate a linear programming problem to optimally allocate firing units to targets.

B. ORGANIZATION OF THE THESIS

Chapter 2 provides a brief background for the FORCEM model. Readers familiar with FORCEM may wish to scan these sections. Chapter 3 contains a description of the current methodology for target acquisition, a discussion of perceived shortcomings, and a discussion of methods to improve the methodology. Chapter 4 contains a description of the current methodology for the allocation of fire support, a discussion of the perceived shortcomings, and the major thrust of the thesis, the development of the Optimization Model for Fire Support Allocation. Chapter 5 is a comparative analysis of the current methodology for fire support allocation with the Optimization Model for Fire Support Allocation.

II. THE FORCE EVALUATION MODEL (FORCEM)

The Army Model Improvement Program (AMIP) consists of three models which simulate combat at three levels: theater, CORPS and division, and battalion task force. The relationship between the three levels of Army models is depicted in Figure 1 on page 4. Note that there are bi-directional flows of information between FORCEM and Vector in Command (VIC) and VIC and CASTFOREM. These flows of information insure that the results from all three models are consistent. FORCEM, the theater level component of AMIP, receives the results of operations from and, in return, sends scenario conditions to the CORPS/Division level model named VIC. In a cascading fashion, VIC then receives battle results from, and in return, sends scenario conditions to the battalion task force model named CASTFOREM.

A. GENERAL MODEL DESCRIPTION

FORCEM is a time step simulation model which processes combat events sequentially in three different functional areas during each time step as depicted in Figure 2 on page 5. These three functional areas are perception update, command and control, and combat activities. The purpose of the perception update functional area is to provide current information concerning locations, strength, tactical posture, and logistics status of both friendly and hostile units. Based on this current information (or perceived data) and predetermined decision rules, the command and control functional area makes tactical command and control (C^2) decisions which include, *e.g.*, maneuver control, assignment of fire support assets (both within divisions and at higher levels), and combat service support (CSS). Finally, the activities functional area executes the decisions made by the Command and Control functional area which entails simulating combat at the division level and higher as well as determining the movement of all units. At the completion of all activities, the perception update process resumes and this completes one simulation cycle in FORCEM.

1. Model Resolution

As previously indicated, FORCEM is a low resolution model. The basic maneuver unit in the model is the division. At CORPS and higher levels, units may be as small as battalions. Theaters, armies, and CORPS have C^2 headquarters units, these command and control headquarters (CAC) may have any combination of the following types of subordinate units assigned to them:

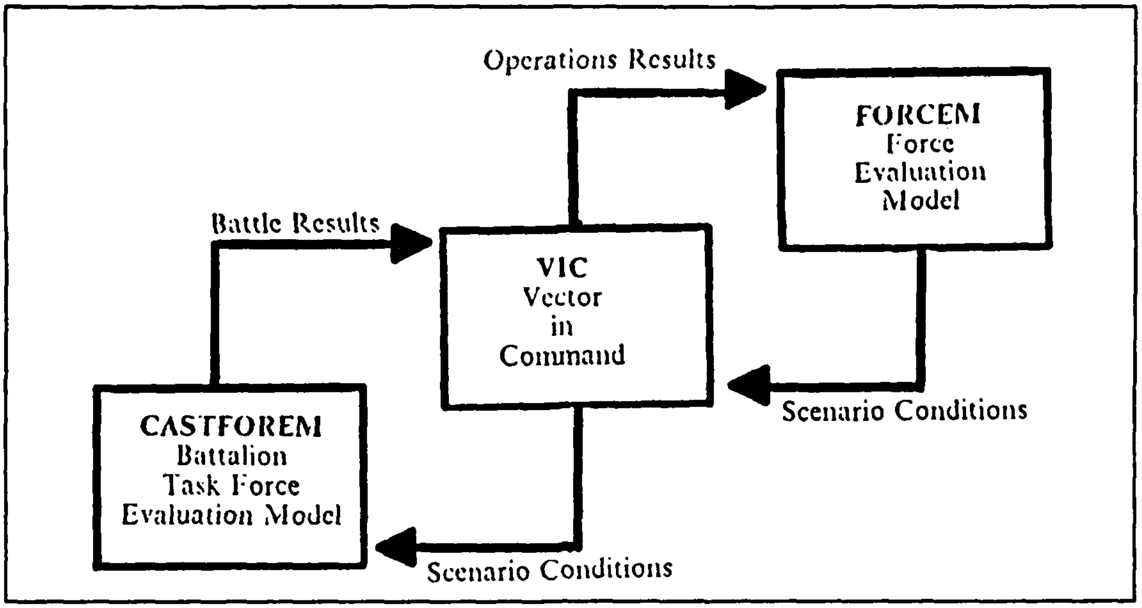


Figure 1. Army Model Improvement Program

1. Maneuver units
2. Support units (CSS)
3. Signal units
4. Intelligence units
5. Engineer units
6. Artillery units
7. Air Defense Artillery units
8. Air Control Centers
9. Air Bases

Each unit in the above list may also include assets such as personnel, supplies, and equipment. Figure 3 on page 6 displays a block diagram depicting a typical force structure for one side of the two opposing armed forces.

2. Representation of Combat Operations

Combat in FORCEM is resolved at two distinct levels, the division level and at the echelons above division level.

a. Combat at the Division Level

Resolution of division-to-division level combat in FORCEM is depicted in Figure 4 on page 7. Prior to the execution of a FORCEM run, an independent division

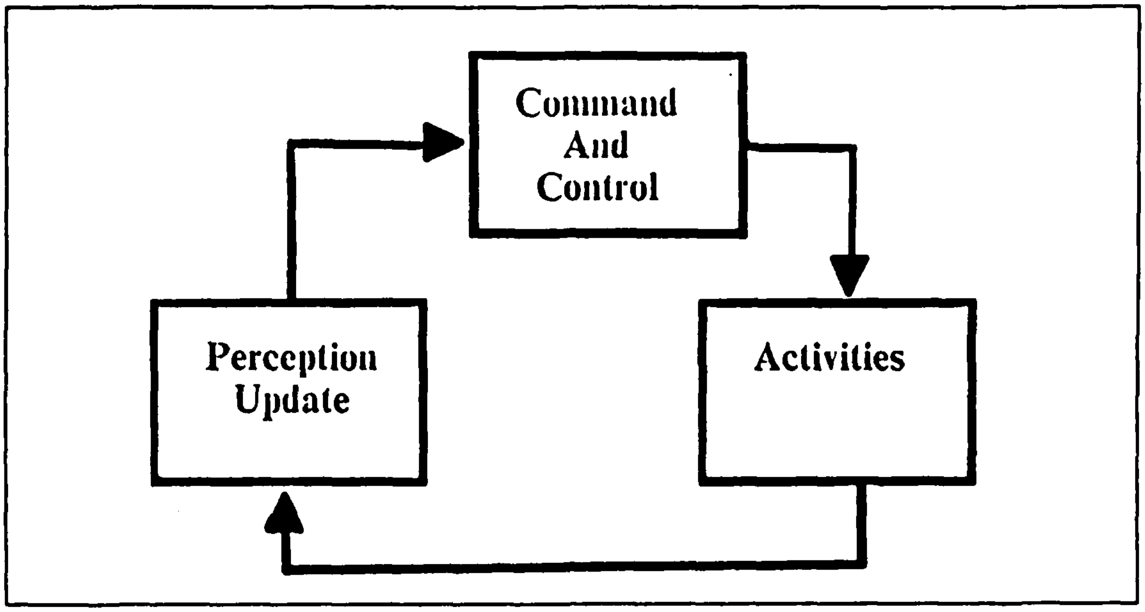


Figure 2. Sequence of Events in One Time Step

combat simulation is executed for particular engagement types (defined in terms of the combat postures of the engaged division level units) and environments (e.g., terrain and weather). Under AMIP, Vector in Command (VIC) simulates the combat at the division level. Until AMIP is fully implemented, however, the model continues to be run with a surrogate division-level model. This surrogate is the Combat Sample Generator (COSAGE). COSAGE runs provide losses of personnel and equipment and expenditures of supplies as a "...function of type of shooter and target, for a given distribution of shooters and targets." [Ref. 2: p. 11] The strengths, losses, and expenditures from COSAGE runs are used to calibrate the attrition coefficients used by FORCEM. This process is known as Attrition Calibration (ATCAL). The multiple coefficients generated are then filed in a library by engagement type and environment. When a division-to-division engagement occurs during a FORCEM run, the model selects an appropriate set of coefficients from the library in order to assess that engagement.

b. Combat at Echelons Above Division

Combat at echelons above the division level can be described as fire support. Fire support in FORCEM is composed of two sub-modules: artillery and air modules. The artillery module includes rockets, cannon, and surface-to-surface missiles, and the air module includes offensive counterair, defensive counterair, deep interdiction, close air support, and reconnaissance.

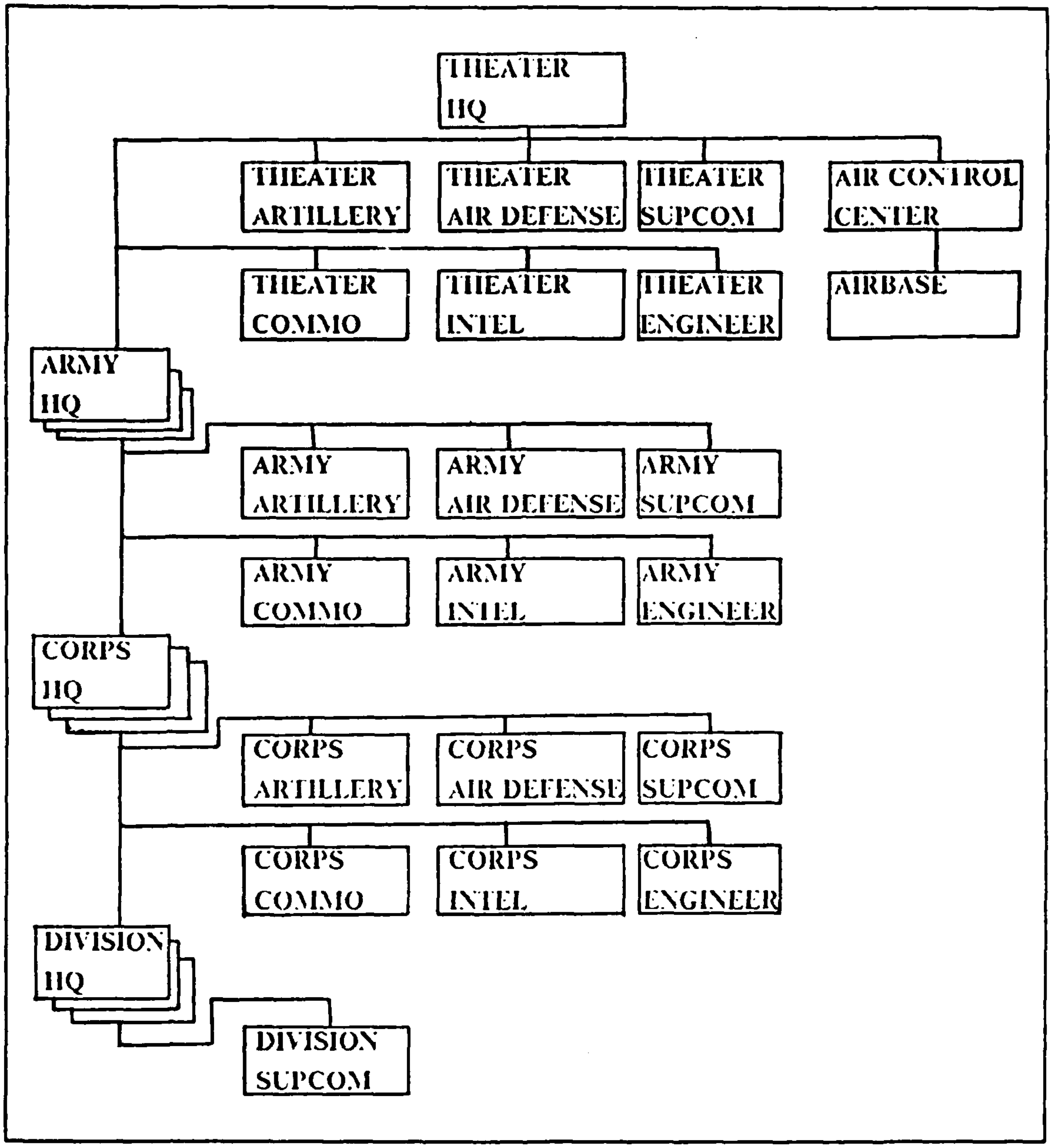


Figure 3. Block Diagram for One Side

Within FORCEM, cannon, rocket, and surface-to-surface missile units are represented as field artillery battalions. These battalions are assigned to command and control headquarters (CAC). Doctrinally, field artillery battalions are given a mission of direct support (DS), Reinforcing (R), General Support (GS), or General Support

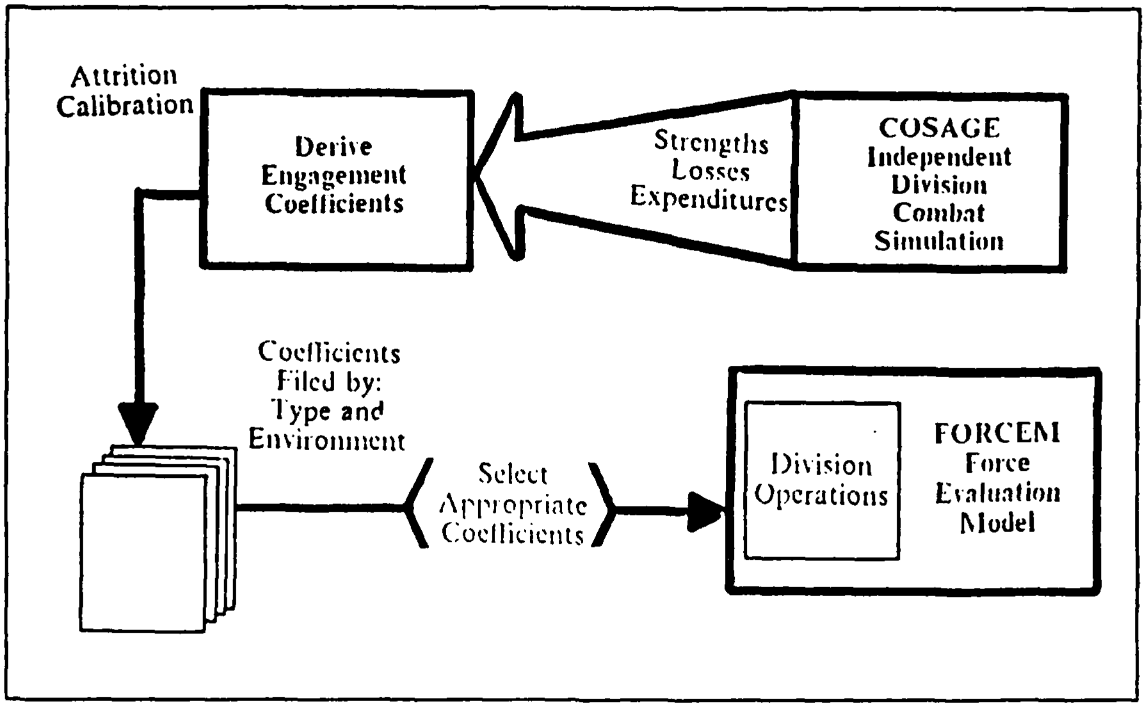


Figure 4. Division Combat

Reinforcing (GSR). These four standard tactical missions are defined in *FM 6-20 Fire Support in the Airland Battle* [Ref. 3: p. 2-9].

DS The field artillery battalion provides field artillery support to a committed maneuver unit, normally a brigade.

R The field artillery battalion augments the fires of a field artillery unit assigned a direct support mission.

GS The field artillery battalion provides field artillery support for the force as a whole, a division or higher level force.

GSR The field artillery battalion provides field artillery support first for the force as a whole and secondly augments the fires of a field artillery battalion assigned a direct support mission.

In FORCEM, the user can directly assign missions to battalions. However, because of the low level of resolution and the division of the battle into two distinct parts, FORCEM allows only three types of missions. These three missions have different meanings than the standard tactical missions described above. Below, we list the three missions with their meanings.

R Field artillery battalions whose fires exclusively augment those of a division.

GS Field artillery battalions who fire exclusively for the CORPS headquarters.

GSR Field artillery battalions who fire first priority for the CORPS headquarters, and secondly augment divisional fires.

Fires in support of divisions contribute to division combat through COSAGE and ATCAL results. Units assigned a GS or GSR mission contribute to the echelon above division battle. Attrition that results from these fires are calculated directly in FORCEM.

B. SUMMARY

This chapter briefly discusses the role of FORCEM within the Army Model Improvement Program and reviews assumptions and level of detail utilized by FORCEM. Two particular issues deserving further analysis are the modeling of the intelligence and target acquisition and the allocation of fire support in FORCEM. Intelligence and target acquisition are two functions critical for resolving combat above the division level. Assumptions concerning the intelligence available to a combat unit greatly influence the ability to acquire targets. Unrealistic assumptions would therefore render the model less meaningful. Equally important is the allocation of fire support to engage acquired targets. In the allocation process, the battalions and type and quantity of ammunition are assigned to engage the targets. If the allocation is not done properly, the combat may be resolved in an unexpected way. Thus, it is the focus of this study to point out shortcomings regarding FORCEM's methods for performing the intelligence and target acquisition and the allocation of fire support and to offer solutions to overcome the shortcomings.

III. INTELLIGENCE AND TARGET ACQUISITION

In this chapter we point out shortcomings of the current method employed by FORCEM for intelligence and target acquisition. Since intelligence and target acquisition are very broad areas, this chapter is limited to intelligence as related to the targeting process of the fire support module, specifically acquisition of field artillery units above the division level. We propose an alternate technique for the acquisition of field artillery units which remedies the shortcomings of the current methodology. This proposal has not been implemented since such implementation can only take place after on-going work at CAA is completed.

A. CURRENT METHODOLOGY

The method currently employed in FORCEM for targeting is very simple. Each CAC has an associated perception range. During the perception update stage of a time step, a list of targets within the perception range of a given CAC is generated. This list is the preliminary target list for the CAC. When this target list is considered by the fire support module, all information about that target is known to the CAC.

B. SHORTCOMINGS OF THE CURRENT METHODOLOGY

The fact that the model is allowed to use all information about a target within the user-defined perception range is known as ground truth. The use of ground truth is not representative of reality. In a real tactical situation the amount and type of information known about units varies by range, type of target unit, type of acquiring unit, and activity of the target unit. Range is not necessarily the best parameter to use in deciding whether or not the location, type of unit, or status of a target is known. One sensor may provide information about a target at a great distance and at the same time the lack or ineffectiveness of a particular sensor may provide little or no information about a target at a much shorter range. The use of a perception range, therefore, limits the ability of the model to portray realistically the intelligence capabilities of modern military forces.

It is well known that NATO and the Warsaw pact have different intelligence capabilities. On the same side different units can have different capabilities because of the differences in their structure and assigned equipment. The current methodology does not allow the model to portray these differences. The perception range can be used for

a limited degree of differentiation; however, it is still lacking since a unit may have a set of sensors which may not have the same range of detection. When a unit has a collection of sensors, there is a problem of selecting a sensor range to represent the unit's perception range in FORCEM.

C. PROPOSED METHODOLOGY FOR TARGET ACQUISITION

In reality, the ability to acquire a target is directly related to the intelligence capability of that unit. Thus, if a unit does not have a sensor required for obtaining particular information about a given target, the simulation model should not assume that the information is available to the unit. Moreover, given that the correct sensor is available, the required information may still be unobtainable due to other circumstantial factors such as the activity level of the target, weather conditions, the number of such sensors, and the amount of time the sensor is in use. Thus, intelligence information also depends on the available sensors in a probabilistic manner. The U.S. Army Concepts Analysis Agency (CAA) has written a work statement for the development of probability distributions for target detections [Ref. 4].

The probability distributions sought by CAA generally represent the probability of detecting aggregated targets such as maneuver divisions which are composed of many different types of units and thus may be detected by a wide variety of sensors. Field artillery units are much simpler targets for acquisition, since they are homogeneous and specific sensors exist with which to detect and identify them. Thus, development of probability of detection for field artillery units should be much simpler than other target types.

Below we describe methods of acquiring field artillery battalions in a tactical situation, and propose a method of using probability of detection to replace the ground truth intelligence now employed by FORCEM. The use of probability of detection allows for more realism in the model. First, the detection is not only a function of the perception range. Second, there can also be different probability distributions for different situations. Finally, each CAC can be differentiated by using different sets of probability distributions.

1. Actual Methods of Acquiring Field Artillery Units

Field artillery units can be acquired in several different ways in an actual combat situation. These include counter-battery radar, sound-flash ranging, moving target locating radar, and direct observation.

a. Counter-battery Radar

Counter-battery radars are the principal asset used by US forces to acquire field artillery units. Soviet forces also have counter-battery radars, but not as many and not as sophisticated as US assets.

Acquisition by radar requires several conditions to be met. Obviously a radar must exist and be in an operational status. Since radars are susceptible to acquisition and countermeasures, they are normally only turned on according to a carefully developed cueing schedule. For an acquisition to occur, a radar must be cued at the time of the firing event. Radars have limited fields of view, requiring that they be oriented in a particular direction and at a certain angle from the horizontal. For an acquisition to occur, a radar must be oriented in the proper direction, with the appropriate angle at the time of the firing event. The final condition is that given that the round flies through the radar beam due to meeting the previous conditions, the radar must track the round for a sufficient period of time to allow an accurate prediction of the point of origin of the round.

b. Sound-flash Ranging

Sound-flash ranging is employed extensively by Soviet forces; US forces have abandoned the technology in favor of radars. Sound-flash ranging is a passive system that requires the use of observers and sound microphones. As with radars, conditions must be met in order to achieve an acquisition using sound-flash ranging. The first condition is that the observers must be in position to observe the flash of firing weapons. As a weapon fires, the observers press a button that starts the system. The sound microphones record the time that the sound of the weapon firing reaches them. The time of the flash and the time the sound reaches the various microphones are processed by a small computer and a location of the weapon is computed.

c. Moving Target Locating Radar

Moving target locating radar could detect a field artillery unit on the move but could not identify it specifically as a field artillery unit. Further intelligence would be required to identify the type of unit that is moving. In order to detect the movement, the following conditions must be met. A radar must exist and be in an operational status. Since radars are susceptible to acquisition and countermeasures, they are normally only turned on according to a carefully developed cueing schedule. For an acquisition to occur, a radar must be cued at the time of movement. Radars have limited fields of view, requiring that they be oriented in a particular direction and at a certain angle from the horizontal. A radar must be oriented in the proper direction, with the appropriate

angle at the time of movement for an acquisition to occur. Finally, given that the unit moves through the radar beam, meeting the previous conditions, the radar operator must track the unit for a sufficient period of time to allow an accurate description of the unit to be developed.

d. Direct Observation

A field artillery unit could be acquired by direct observation. A large number of sensors exist that could acquire a unit by direct observation. These sensors include, but are not limited to, aerial reconnaissance, long range patrols, forward looking infrared radars, etc. Conditions to be met for acquisition by these devices include the existence of the sensor and an orientation or path sufficiently close to the target firing unit to allow detection.

2. Modeling the Acquisition of Field Artillery Units

a. Detection Probability Distributions

Probability distributions for the detection of field artillery units by radar and sound-flash ranging should be easy to develop, given an appropriate set of data. For artillery acquiring systems, the probability of detection is a function of the number of rounds fired by the target, the number of radars available to the CAC, the frontage of the CAC sector, the search sector of the radar, the operating characteristics of the radar, and the collection plan, specifically the proportion of time that the sensor is expected to be operating. Probability of detection distributions for the various combinations of conditions can be approximated using a high resolution combat simulation model such as CASTFOREM. The resulting probability distributions can be used to calculate the probability that a given target is detected. If this probability is greater than a predetermined value, the target is considered detected and included on the preliminary target list.

b. Implementing Detection Probability Distributions in FORCEM

Assuming that the probability of detection distributions are be obtained, a method of using them in a deterministic model such as FORCEM is specified in this section. Discussion here will be limited to counter-battery radars and sound-flash bases since these are the principle methods of locating field artillery units. These systems also have the advantage of certain knowledge of the target type, that is, they only detect field artillery, therefore any detected targets are known to be field artillery.

Appendix A is a flow chart depicting a proposed methodology for acquiring field artillery units as targets. The simplified steps of the methodology are:

1. Develop the perceived target list.

All field artillery units within the acquisition range of the longest ranging radar or sound-flash base will be on the perceived target list.

2. Reduce the number of targets on the perceived target list.

The firing activity of each target in the previous time step is determined. If the target did not fire in the time step, it cannot be acquired by radar or sound-flash ranging. Targets that have not fired will be eliminated from the perceived target list.

3. Determine the probability of detection by radar and sound-flash bases.

These probabilities are determined from the probability distributions described above, given the level of firing activity of the target.

   a. One type of system available.

   If only one type acquisition system is available, and the probability of detection is above the user-specified threshold, the target will be added to the preliminary acquisition list. If the probability is below the threshold, the target will be discarded.

   b. Both type of systems available.

   If both types of systems are available, each probability is compared to the threshold. If either of the detection probabilities is above the threshold, the target will be added to the preliminary acquisition list. If the probability is below the threshold, a joint probability will be computed. If this probability is above the threshold, the target will be added to the preliminary acquisition list. If the probability is below the threshold, the target will be discarded.

4. Determine targets on the preliminary target list.

This step decides which targets on the acquisition list should be passed to the fire support allocation process. Only those targets that are within the engagement range of assets available to the CAC should be on the preliminary target list passed to the fire support module. This will reduce the burden on the fire support module by eliminating targets that are out of range and cannot be engaged.

D. SUMMARY

The current version of FORCEM utilizes the perception range as the sole factor for deciding whether or not complete intelligence information about a target is available to a CAC. It is pointed out in this chapter that intelligencc information realistically depends on many factors besides the perception range, thereby rendering the intelligence and target acquisition functions of FORCEM unrealistic. Currently, CAA is in the process of remedying this unrealistic portrayal of intelligence and target acquisition through the use of probability distributions. This chapter provides a method to implement the use of such distributions for the acquisition of field artillery units.

IV. ARTILLERY FIRE SUPPORT ALLOCATION

Fire support in FORCEM includes both field artillery support and air support. This chapter limits the discussion of fire support to the echelon above division artillery in FORCEM. Only artillery battalions that receive a mission of GS and GSR as defined by FORCEM are considered. Additionally, only conventional fires are considered; nuclear and chemical fires are handled in another module of FORCEM. This discussion is further restricted to a discussion of a Blue side example.

A. CURRENT METHODOLOGY

The first step of the fire support allocation process is the development of a perceived target list. This list includes all targets within a user-specified perception range of the CAC doing the targeting. An initial feasibility check is made to ensure that each target on the perceived target list is within range of at least one battalion assigned to the CAC. If this feasibility check fails, the target is discarded from fire support consideration. If the target is within range, it is added to the preliminary target list. Fire support allocation in FORCEM is essentially composed of two parts: target prioritization and weapons selection. An important function also performed by the fire support module is damage assessment or attrition. Damage assessment will be included in this discussion as the logical result of the fire support allocation process. The target prioritization process determines the relative importance of all targets on a CAC's preliminary target list. Weapons selection involves selecting the appropriate artillery battalion, type of munition, and amount of munition with which to engage a particular target.

1. Target Prioritization

Each target on the preliminary target list is considered in turn by the prioritization routine. This routine accesses a user-provided priority matrix associated with the CAC in question. This matrix has three dimensions:

1. Dimension 1 - The mission of the target-acquiring CAC.
    a. Attack.
    b. Defend.
    c. Delay.
    d. Withdraw.

2. Dimension 2 - The type target being engaged.
   a. Command and control units.
   b. Maneuver divisions.
   c. Ports.
   d. Artillery battalions.
   e. Communications units.
   f. Support commands.
   g. Positioning of Material, Configured to Unit Sets (POMCUS) sites.
   h. Supply convoys.
   i. Personnel convoys.
   j. Airbases.
   k. Air defense units.
3. Dimension 3 - The user established range band in which the weapon-target range falls.

The result of accessing this matrix is a single number that represents the priority of the target. As each target on the preliminary target list receives its priority it is filed in a priority ordered list, highest priority targets at the top of the list.

Subsequent to this initial priority ordering, the priority numbers of targets specified by the user to be considered for mass firing and those identified to be components of the main attack against the CAC are doubled. This action has the effect of moving these targets to the top or near the top of the priority list.

2. Weapons Selection

Weapons selection occurs in two stages: consideration for engagement with missiles and consideration for engagement by cannon or rocket fire.

a. Surface-to-Surface Missile Selection

Each target in the priority ordered list is considered in turn for missile engagement. This decision is made by accessing a three dimensional array for non-nuclear missile engagement.

1. Dimension 1 - The side
   a. Blue
   b. Red
2. Dimension 2 - The target type being engaged. (Previous description)
3. Dimension 3 - The range band in which the weapon-target range falls. (Previous description)

This matrix provides a yes/no decision on whether a missile is to be fired on a particular target. If a missile is to be fired, the matrix also provides the type of missile to be fired as well as number of rounds. Currently, missile battalions are limited to two engagements per combat cycle. For a missile to be fired, an appropriate battalion with sufficient ammunition and engagements remaining must be found in the CAC. If none are available a missile will not be fired. If a missile is not to be fired, the target is next considered for engagement by cannon or rockets.

b. Cannon or Rocket Selection

The targets on the priority ordered list are considered for cannon/rocket engagement. The first step of the cannon/rocket weapons selection routine is a feasibility check. If a target is within range of at least one cannon or rocket battalion, the process is continued for that target. If a target is not within range, it is discarded from fire support consideration and the next target on the priority list is considered.

If a target is within range of a cannon or rocket battalion, a user supplied weapon selection array is accessed. This matrix is used to select the type of artillery weapon system that the user wishes to employ against a specific target type in a specific range band. The dimensions of the matrix are as follows:

1. Dimension 1 - The side of the engaging CAC.
2. Dimension 2 - The target type being engaged. (Previous description)
3. Dimension 3 - Weapons selection range band. (one through four)
4. Dimension 4 - Mass target flag. (yes or no indicator)
5. Dimension 5 - Artillery Weapon System Demand. Up to nine prioritized weapon selections for each target type, range band combination. This dimension includes a specific weapon as well as number of rounds to fire.

The result of accessing this matrix is a set of up to nine different priority ordered weapon selections. Each weapon selection is considered in priority order. Cannon and rocket battalions are limited to a user defined number of engagements per combat cycle. If a battalion within the CAC has the appropriate weapon, the logic determines if there is sufficient ammunition on hand and engagements remaining to complete the engagement. If sufficient ammunition is on hand, and engagements remain for this battalion, the engagement is scheduled on a program of fires with the following parameters:

1. The target-acquiring CAC.
2. The target type.

3. Weapon asset used (munition).
4. Number of missiles or rounds fired.
5. The target area in square meters.
6. The target unit identification number.
7. The battalion identification number.
8. The number of engagements against this target.
9. Mass target flag.
10. The number of massing battalions, if any.
11. The number of battalion volleys fired.
12. The number of rounds fired in a battalion volley.

If a considered battalion does not have sufficient ammunition on hand or engagements remaining, the other battalions in the CAC with the particular weapon are considered. If no battalions with the particular weapon have sufficient ammunition on hand or engagements remaining, the next weapon selection on the priority list is considered. This process is continued until a feasible weapon selection from the priority list is found, or all possible combinations of weapon selections and battalions are exhausted. If a feasible selection is found the engagement is written as before. If a feasible selection is not found the target is discarded from fire support consideration and the next target on the priority list is considered.

The process above continues until all targets on the priority ordered list have been considered. The result of the process is a program of fires to be used by the damage assessment logic.

3. Fire Support Damage Assessment

Attrition from fire support engagements is determined separately for surface-to-surface missiles and cannon/rockets. Each engagement in the program of fires is considered by the appropriate subroutine. For each target, FORCEM considers 12 generic target components.

1. Battle tanks.
2. Armored personnel carriers (APC).
3. Trucks.
4. Recovery vehicles.
5. Artillery pieces.
6. Air defense weapons.

7. Aircraft and helicopters.
8. Personnel.
9. Petroleum, oils, and lubricants (POL).
10. Ammunition.
11. Repair Parts.
12. Runways.

Each of these target components may include several different types of equipment. For example, there may be several varieties of tanks organic to a target. These data are specified by user input in the list of assets associated with every target's force structure. Fractional damage to these target components is computed in the surface- to-surface missile and cannon/ rocket artillery damage assessment calculations.

a. Surface-to-Surface Missile Damage Assessment

The number and type of missiles fired in an engagement are calculated in the weapon selection routine. Given the type of missile to be fired, the target type, and the engagement range, user input files are accessed to determine circular probable error, pattern size, lethal area, and sub-munitions per missile. These data are used to compute fractional damage of the target using equations developed by the Army Material Systems Analysis Activity (AMSAA). [Ref. 1: pp. 31-32]

Fractional damage is computed for each target component. The number of target components type i killed is the number of target components type i in the target times the fractional damage.

b. Cannon or Rocket Damage Assessment

From the weapons selection routine, the number and type of rounds to be fired is known. The number of rounds determines the number of battalion sized volleys to be fired. Since the targets are large aggregated targets, the user must specify the percentage of a target that is at risk from a battalion volley. For example, when an artillery battalion is the target, a reasonable part of the battalion for targeting might be a battery. In this case one-third of the battalion's weapon systems, personnel, POL (*i.e.*, petroleum, oils, and lubricants), ammunition, and repair parts would be at risk. The user must also specify the area in square meters that this sub-element of the target would occupy.

The fire support module uses the AMSAA "super-quickie" algorithm to calculate composite lethal areas associated with battalion volleys against the 12 target components.

Each target component has a different lethal radius; therefore, fractional damage must be computed separately for each target component. Fractional damage is computed by multiplying the lethal are of one volley times the number of volleys, all divided by the target area.

Given the fractional damage computations, the number of kills by target component is calculated next. The number of kills is the number of target components of a particular type present in the target, times the fractional damage.

B. SHORTCOMINGS OF THE CURRENT METHODOLOGY

Several shortcomings exist in the current methodology of fire support allocation in FORCEM. Four are addressed in this thesis: analyst input, target prioritization, firing battalion selection, and ammunition accountability.

1. Analyst Input

As described previously the current methodology for artillery fire support allocation requires significant user input to accomplish the weapon/round selection for an engagement. For each side the user must specify weapon selection parameters before the model is run. For each target in each range band the user must list in priority order the weapon/round type to be fired as well as the number of rounds to be fired. Since there are 11 target types, four range bands for weapon selection, and nine potential weapon selections, this represents a requirement to enter 396 data elements for each side. Further, within each subset of range band and target type, these entries must be listed in priority order. While some of these entries may be null, this represents significant work to do the job properly.

The effort to input these data is further complicated by the fact the numbers do not represent data, but decisions that would be made in combat based on a variety of factors. These factors include, but are not limited to, ammunition on hand, expected resupply time, the number of other targets available, the quality of intelligence about the target, the current capability of the target, and the commander's intent. Clearly each of these factors is dynamic and will change significantly over time. The current methodology requires that a decision be made based on these factors before the values of the factors are known.

2. Target Prioritization

The target prioritization methodology relies strictly on an ordinal prioritization scheme, based on target type, range band, and mission of the CAC. This prioritization remains in effect throughout the run because there is no provision to update the values

in the priority matrix. This supposes that the relative importance of two targets to a CAC remains fixed through the length of a run. This ignores the fact that relative value and strength of targets change over time.

As an example of a problem with the current prioritization methodology, consider the following example. Two targets of the same type, with the same parent CAC, are within the same range of the engaging CAC. By the current methodology each would have the same priority and would be engaged with the same number of rounds of ammunition. An additional fact, not known to the current methodology, is that one target is at 50 percent strength, because it was previously engaged, while the other is at 100 percent strength. Clearly these two targets are not equivalent as treated by the current methodology.

3. Firing Unit Selection

Firing battalion selection is accomplished in a loop. Battalions at the top of the list are always considered for being assigned an engagement first. The first battalion in the list that can range the target and has sufficient resources in terms of ammunition and allowed engagements remaining will be assigned the mission. This top-down ordering, and engagement by engagement selection, may limit the number of engagements that can be accomplished in a given time cycle.

As an example of the problem with the firing battalion selection methodology, consider the following example. Two targets remain to be engaged, targets X and Y, listed in priority order. Further two battalions, B1 and B2, are available and listed in that order for selection consideration. Target X has a requirement of 100 rounds and target Y has a requirement of 200 rounds. Battalion B1 has 200 rounds available while battalion B2 has 100 rounds. Clearly, sufficient ammunition is available to engage both targets, however due to the structure of the current methodology, target X will be engaged by battalion B1, and neither battalion will have sufficient ammunition available with which to engage target Y.

As an example of another problem with the firing battalion selection methodology, consider the following example. Two targets remain to be engaged, targets X and Y, listed in priority order. Further two battalions, B1 and B2, are available and listed in that order for selection consideration. Target X has a requirement of 200 rounds and target Y has a requirement of 200 rounds. Battalion B1 has 199 rounds as does battalion B2. The difference between 199 rounds and 200 rounds is very minor in real life. A fire direction officer faced with a recommended solution of 200 rounds but having only 199 rounds remaining would likely fire the 199 rounds and not be overly concerned. The

current battalion selection methodology has no such flexibility and neither target in this example would be engaged.

4. Ammunition Accountability

FORCEM currently accounts for ammunition at the battalion level by weight, not by round or type. The battalion is allowed to fire the engagement if sufficient ammunition weight remains in the battalion to fire the number of rounds required for the engagement. For determining effects the specific type of round fired must be known in addition to how many. In order to determine which type of round is fired at a particular target, FORCEM assumes that the "best" possible round in terms of effects is selected. This assumption is very likely to overstate the effects achieved by artillery over the course of a run. Additionally, the assumption of the "best" ammunition always being available may lead to firing amounts of rocket assisted projectile (RAP) and improved conventional munition (ICM) that are not supported by the logistics base.

C. AN OPTIMIZATION MODEL FOR FIRE SUPPORT ALLOCATION

The linear programming (LP) model described below assigns firing battalions to targets and determines the type and number of volleys of ammunition to fire so as to maximize the loss of target value which can be inflicted upon the available targets. By using the LP model to make the fire support decision, (1) analyst input of the form described in Section B.1 is no longer required, (2) target prioritization is irrelevant since the LP model chooses targets in an optimal manner, (3) firing units are selected optimally, and (4) the ammunition accountability is incorporated into constraints at a higher level of detail. We formulate the linear programming problem as follows:

1. Index Use

a. Firing Battalions

The index used to represent battalions is the letter i.

A battalion is defined to be a cannon or rocket battalion assigned a general support (GS) or general support reinforcing (GSR) mission to the CAC being processed by FORCEM. Further the battalion must have sufficient personnel and tube strength available to be considered operational as defined by the user. Non-operational battalions will not be included in this set. The number of such battalions will determine the size of the index set.

b. Targets

The index used for targets is the letter j.

Targets on the preliminary target list will be considered targets for this model. The number of such targets will determine the size of the index set.

c. Ammunition Types

The index used for ammunition types is the letter m.

Ammunition types indexed are:

1. High Explosive (HE)
2. Rocket Assisted Projectile (RAP)
3. Improved Conventional Munition, Total (ICM)
4. Improved Conventional Munition, Used in Range Band One (ICM1)
5. Improved Conventional Munition, Used in Range Band Two (ICM2)

Additional ammunition types can be indexed as required.

2. Given Data

The following data are required to implement this model. Some of the data are already present in FORCEM. Where the data are not currently available, a general method of obtaining the data is recommended. Specific instances of data are discussed in Chapter 5.

a. Current Value of a Target (VALUE)

$VALUE_j$ is the estimated current value of target j to the CAC. A target's value is a function of the mission of the CAC headquarters it opposes, its perceived mission, range from the CAC to the target, and the specific type of target. At the beginning of hostilities it is likely that significant information will be known about all targets opposing a CAC. This knowledge would be represented in the model by the user input of a specific value for each target on the battlefield. These specific values could come from any number of sources. One promising source is The United States Army Training and Doctrine Command's System Information Manager's Office for the Advanced Field Artillery Tactical Data System (AFATDS). AFATDS is the next generation fire direction computer for the field artillery. One aspect of the design of this system is a target value analysis method of assigning numerical values to targets. This method is promising since it is a system that will be fielded and will actually be used to make targeting decisions in a tactical situation. Using the same methods in the model will insure more realism in the simulation. The current value of a target is obviously changing over time. It may not be desirable to re-compute that value of a target with

each time step because this may assume possession of knowledge about a target that is not available. If this is the case, another method of determining the current value of a target after the initial value is required. One method is to assume that effects predicted against a target by air and artillery actually occurred and to change the value of the target by the appropriate attrition to determine the new value of the target. If this method is used, the targets must be allowed to replenish themselves. An estimate of value replaced over a time step can also be made. The current value of a target will be the initial value minus changes due to attrition plus changes due to replenishment. FORCEM has data to support the attrition and replenishment. The initial target values will be input by the user.

b. Effectiveness of a Volley (EFF)

EFF_{imj} is the effectiveness of battalion i firing one volley of ammunition m at target j, expressed as a percentage of $VALUE_j$. "Joint Munition Effectiveness Manuals for Surface-to-Surface Weapons (JMEM/SS) provide guidance for determining the expected fraction of casualties to personnel targets or damage to materiel targets." [Ref. 5: p. 4-11] The JMEM/SS should provide the effectiveness values used in this model. As with any prediction, JMEM/SS are not totally accurate. *FM 6-141, Field Artillery Target Analysis and Weapons Employment Nonnuclear*, asserts "...the method of averaging data used for the tables will result in less damage being realized for approximately 50 percent of the rounds, and conversely, greater damage for the other 50 percent of the rounds." [Ref. 5: pp. 4-11, 4-12] For the purposes of a theater level model this degree of accuracy is sufficient.

c. Minimum Effects Desired (MINEFF)

$MINEFF_j$ is the minimum effects desired before allowing an engagement of target j, expressed as a percentage of $VALUE_j$. These data are currently not maintained in FORCEM. These data would be input by the user and would reflect a measure of the commander's attack criteria. If sufficient effects would not be achieved, do not engage this target. Since the air module is currently separate from the artillery model, this would allow a mechanism for passing a target to the air module because of the ineffectiveness of available artillery. A likely value for this variable would be in the range of three to ten percent. If a user does not wish to use this feature, an entry of zero would effectively eliminate the constraint based on this variable.

d. Maximum Effects Desired (MAXEFF)

$MAXEFF_j$ is the maximum effects desired when engaging target j, expressed as a percentage of $VALUE_j$. These data are currently not maintained in FORCEM.

$MAXEFF$ is closely related to $MINEFF_j$ above. It also serves as a measure of the commander's attack criteria, but at the other end of the scale. This recognizes the fact that the effectiveness of a battalion is not strictly linear. A target may be attrited to the point that it ceases to function, even though it has some value remaining. A likely value for this variable would be 30 percent [Ref. 5: p. 2-2]. These data serve a further purpose of providing a method of limiting the amount of ammunition expended. Clearly this model would attempt to fire all available ammunition, limited only by time available. Entry of these data indirectly imposes a limit on how much ammunition is consumed, insuring that the ammunition is not wasted on attempting to engage a target that is already combat ineffective.

e. Table of Organization and Equipment Tube Strength (TOETUBES)

$TOETUBES_i$ is the number of howitzer tubes or missile launchers assigned by Table of Organization and Equipment (TOE) to battalion i. These data are present in FORCEM, but not used in this manner. All battalions are assumed to have the same number of tubes or launchers. These data allow flexibility in portraying artillery organizations and would be input by the user at the beginning of a run based on the TOEs of the battalions involved in the battle.

f. Current Volley Size (CURTUBES)

$CURTUBES_i$ is the number of tubes or launchers currently available in battalion i. This variable also represents the number of rounds in one volley fired by battalion i. These data are present in FORCEM, but are currently used only to determine if a battalion has sufficient tube strength to be considered available for firing. The number of rounds fired at a particular target is fixed and not related to the tube strength of the battalion firing.

g. Battalion Available Time (AVAIL)

$AVAIL_i$ is the fraction of time unit i is expected to be able to deliver fires during the time step. These data are not present in FORCEM. This variable, together with $TIME_{i,m}$, is used to eliminate the rather arbitrarily determined limit on engagements per cycle which currently exists in FORCEM. Based on the mission of the CAC controlling the battalion and professional judgment on the part of the user, a realistic estimate of the time a battalion is likely to be in position able to fire can be made. This value would take into consideration movement, emplacement, displacement, and other non-firing times.

h. Time to Fire One Volley (TIME)

$TIME_{im}$ is the time required by battalion i to fire one volley of ammunition m, expressed in minutes. These data are not present in FORCEM, but can be estimated and input by the user. A source for these data would be Army Test and Evaluation Program (ARTEP) manuals, or equipment operational tests. These data could be altered if desired to allow for the differing capabilities of battalions based on their experience and training. For example, a recently activated reserve battalion may have times that are longer than a regular army battalion. These data are used together with $AVAIL_i$ to determine if a battalion has sufficient time available in a time step to complete its assigned fire missions.

i. Ammunition Available (AMMOAVAIL)

$AMMOAVAIL_{im}$ is the number of rounds of ammunition type m on hand at battalion i at the beginning of the time step. These data are available in FORCEM in this form.

j. Unit-Target Range (RANGE)

$RANGE_{ij}$ is the range from battalion i to target j, expressed in decameters. These data are available in FORCEM in this form.

k. Maximum Achievable Range (MAXR)

$MAXR_{im}$ is the maximum range that battalion i can achieve if firing ammunition j, expressed in decameters. These data may also correspond to the end of a range band for an ammunition type that has more than one range band. These data are available in FORCEM in this form.

l. Minimum Achievable Range (MINR)

$MINR_{im}$ is the minimum range that battalion i can achieve if firing ammunition j, expressed in decameters. These data may correspond to the beginning of a range band for ammunition types with more than one range band, such as ICM. Additionally the user could limit the use of RAP ammunition by establishing a minimum range for its use, precluding the use of RAP at ranges achievable by conventional HE. These data are available in FORCEM in this form.

m. Length of One Time Step (TIMESTEP)

TIMESTEP is the length in minutes of one time step in the simulation. Although the standard time step is 12 hours (720 minutes) in FORCEM, the value is parameterized here to allow deviation from that standard.

3. Decision Variables

a. Number of Volleys to Fire (VOLLEY)

The primary decision variable is $VOLLEY_{ijm}$, which is the number of volleys of type m ammunition to be fired by unit i at target j. This decision variable, together with the required input data, will provide FORCEM all the information it needs to complete its engagement files.

b. Improved Conventional Munition Allocation (ALLOC)

Since Improved Conventional Munitions (ICM) appear to have significantly differing effects over two range bands [Ref. 1: p. 29], ICM is treated as two separate ammunitions. It is necessary to cause the model to allocate ICM to one of the two range bands since the ammunition on hand can be used for either. This decision variable $ALLOC_{im}$, together with the data $AMMOAVAIL_{im}$, serves that function. If range bands for other ammunitions were desired, similar procedures would be employed.

4. Objective Function

The objective of this linear program formulation of the fire support allocation process in FORCEM is to allocate fire support such that the maximum damage in terms of target value can be inflicted . ᵔn available targets. A mathematical statement of this objective is equation (4.1).

$$MAXIMIZE \quad \sum_{j}\sum_{m}\sum_{i} VOLLEY_{ijm} \times EFF_{imj} \times \frac{CURTUBES_i}{TOETUBES_i} \times VALUE_j \tag{4.1}$$

The product of $VOLLEY_{ijm}$, the number of volleys of type m ammunition to be fired by battalion i at target j, and EFF_{imj}, the effect of one volley of type m fired by battalion i at target j, is the effect on target j if all tubes authorized to battalion i were available to fire. This effect must be reduced if all of battalion i's authorized tubes are not available for firing. $\frac{CURTUBES_i}{TOETUBES_i}$ scales the effects based on the number of tubes available. The product of the previous terms with $VALUE_j$ is the value of target j attrited by engaging target j with $VOLLEY_{ijm}$ volleys of ammunition m fired by battalion i. Summing over i, m, and j yields the value of the objective function which should be maximized.

5. Constraints

a. Target in Range of the Battalion

For an engagement to take place the intended target must be within range of the battalion. The minimum and maximum ranges that a battalion can achieve are functions of the weapon system of the battalion, and the particular round selected for the engagement. In the strict sense, this is a constraint; implementation of most linear program solvers allows this restriction to be handled in the pre-processor. This is accomplished by limiting the generation of variables and equations to ensure that no infeasible solutions are considered. This method is employed in this case. The data $MAXR_{im}$, $MINR_{im}$, and $RANGE_{ij}$ are used to limit the generation of equations and variables to feasible battalion, target, and ammunition triples.

b. Availability of Ammunition

Sufficient ammunition must be on hand for unit i to complete all of its engagements. This constraint for non-ICM ammunition is enforced by equation (4.2).

$$\sum_j VOLLEY_{ijm} \times CURTUBES_i \leq AMMOAVAIL_{im} \qquad \forall i,m \neq ICM1,ICM2 \qquad (4.2)$$

$VOLLEY_{ijm}$ is the number of volleys of type m ammunition fired by battalion i at a target j. $CURTUBES_i$ is the current tube strength of firing battalion i. The total number of rounds of ammunition m fired by battalion i at target j then, is the product of $VOLLEY_{ijm}$ and $CURTUBES_i$. Since a battalion may fire the same ammunition at several targets during a time step, the total number of rounds of type m fired by battalion i during a time step is the sum over all targets j that were engaged with ammunition m. This sum must be less than or equal to the amount of ammunition type m available to battalion i. This constraint must hold for all battalions i firing munition m except where m is ICM1 or ICM2.

For ICM ammunitions this constraint is enforced by equations (4.3) and (4.4).

$$\sum_j VOLLEY_{ijm} \times CURTUBES_i \leq ALLOC_{im} \qquad \forall i,m = ICM1,ICM2 \qquad (4.3)$$

$$ALLOC_{i,ICM1} + ALLOC_{i,ICM2} \leq AMMOAVAIL_{i,ICM} \qquad \forall i \qquad (4.4)$$

The first equation insures that sufficient ICM is allocated for each decision to fire $VOLLEY_{ijm}$ volleys of ammunition from battalion i given the current tube strength, $CURTUBES_i$, of battalion i. The second equation insures that the amount of ICM allocated to the range bands does not exceed the total amount of ICM on hand.

c. Availability of Time

Sufficient time must be available in a time step for battalion i to complete all of its engagements. This constraint is enforced by equation (4.5).

$$\sum_m \left\{ TIME_{im} \times \left(\sum_j VOLLEY_{ijm} \right) \right\} \leq AVAIL_i \times TIMESTEP \qquad \forall i \qquad (4.5)$$

$VOLLEY_{ijm}$ is the number of volleys of type m ammunition fired by battalion i at a target j, summing over all targets j yields the total number of volleys of type m ammunition fired by battalion i. The product of this term with the amount of time required to fire a volley of ammunition m by battalion i ($TIME_{im}$) yields the total time spent firing ammunition m. Summing over all ammunition types m yields the total time that battalion i spends firing over the time step. This value must be less than or equal to the percentage of time battalion i is available ($AVAIL_i$) times the number of minutes in the time step ($TIMESTEP$). This constraint must hold for all battalions i.

d. Minimum Effects

Sufficient effects must be achieved against target j before allowing an engagement. This constraint is enforced by equation (4.6).

$$\sum_m \sum_i VOLLEY_{ijm} \times EFF_{imj} \times \frac{CURTUBES_i}{TOETUBES_i} \geq MINEFF_j \qquad \forall j \qquad (4.6)$$

The product of $VOLLEY_{ijm}$, the number of volleys of type m ammunition to be fired by battalion i at target j, and EFF_{imj}, the effect of one volley of type m fired by battalion i at target j, is the effect on target j if all tubes authorized to battalion i were available to fire. This effect must be reduced if all of battalion i's authorized tubes are not available for firing. $\frac{CURTUBES_i}{TOETUBES_i}$ scales the effects based on the number of tubes available. The product of the previous terms with $VALUE_j$ is the value of target j

attrited by engaging target j with $VOLLEY_{ijm}$ volleys of ammunition m fired by battalion i. Summing over all ammunition types m and battalions i yields the effects achieved over all engagements against target j. This value must be greater than or equal to the minimum desired effects specified for an engagement ($MINEFF_j$). This constraint must hold for all targets j.

e. *Maximum Effects*

Effects must not be allowed to exceed the effects desired by the commander. This constraint must be placed into effect to prevent the model from attriting a target's value below zero. This constraint is enforced by equation (4.7).

$$\sum_{m}\sum_{i} VOLLEY_{ijm} \times EFF_{imj} \times \frac{CURTUBES_i}{TOETUBES_i} \leq MAXEFF_j \quad \forall j \tag{4.7}$$

The product of $VOLLEY_{ijm}$, the number of volleys of type m ammunition to be fired by battalion i at target j, and EFF_{imj}, the effect of one volley of type m fired by battalion i at target j, is the effect on target j if all tubes authorized to battalion i were available to fire. This effect must be reduced if all of battalion i's authorized tubes are not available for firing. $\frac{CURTUBES_i}{TOETUBES_i}$ scales the effects based on the number of tubes available. The product of the previous terms with $VALUE_j$ is the value of target j attrited by engaging target j with $VOLLEY_{ijm}$ volleys of ammunition m fired by battalion i. Summing over all ammunition types m and battalions i yields the effects achieved all engagements against target j. This value must be less than or equal to the maximum desired effects specified for an engagement ($MAXEFF_j$). This constraint must hold for all targets j.

D. SUMMARY

This chapter has presented the current and a proposed replacement methodology for handling the fire support allocation function in FORCEM. The two methodologies will be contrasted in the next chapter using an unclassified FORCEM run for one timestep for one CAC.

V. COMPARATIVE ANALYSIS

In order to perform comparative analysis, the United States Army Concepts Analysis Agency (CAA) provided an unclassified run of targets and battalions for one Command and Control Headquarters (CAC). Data were extracted from this run and applied to the model developed in Chapter 4. This Chapter provides the results of fire support allocation using the two methodologies and a comparison of their results.

A. FORCEM DATA

The data concerning battalions and targets are common to both methodologies and will only be listed once. Targets on the preliminary target list and battalions available are used with the optimization model to compare results with the current FORCEM methodology.

1. Available Battalions

For this CAC, 12 battalions are available. One of the battalions is equipped with M110A2, 203mm self propelled howitzers. The other eleven are equipped with M109A3, 155mm self propelled howitzers. TOE tube strength ($TOETUBES_i$), current tube strength ($CURTUBES_i$), and ammunition available ($AMMOAVAIL_{im}$) as defined in the optimization model may be found in Table 7 on page 46. Weapon system maximum ranges for particular ammunition types are as seen in Table 1 on page 31. These data correspond to $MAXR_{im}$ as defined in the optimization model. For ICM2 the value of $MINR_{im}$ will be the value of $MAXR_{im}$ plus one meter; $MINR_{im}$ for all other ammunition types will be zero.

Table 1. WEAPON SYSTEM MAXIMUM RANGES (METERS)

Weapon System	Munition Type			
	HE	RAP	ICM1	ICM2
M109A2/3 155MM	18,100	24,000	10,000	18,100
M110A2 203MM	22,000	30,000	10,000	22,000
M270 MLRS	NA	NA	NA	30,000

2. Targets

a. *Perceived Target List*

The perceived target list generated for the CAC included 103 targets, each of which is within the user specified perception range of the CAC. Table 2 provides the type and number of each target on the perceived list.

Table 2. PERCEIVED TARGET LIST

Target Type	Number
Command and Control Units	2
Maneuver Divisions	23
Artillery Battalions	31
Communications Units	17
Support Commands	17
Supply Convoys	13
Total	103

b. *Preliminary Target List*

The preliminary target list is generated from the perception list. All targets on the perception list that are within range of at least one battalion in the CAC are included on the preliminary target list. Of the 103 targets on the perception list, 82 were within range of at least one battalion. Targets on the perception list were of the type and number seen in Table 3.

Table 3. PRELIMINARY TARGET LIST

Target Type	Number
Command and Control Units	2
Maneuver Divisions	15
Artillery Battalions	18
Communications Units	17
Support Commands	17
Supply Convoys	13
Total	82

Specific information about targets on the preliminary target list, such as target type, parent CAC's mission, weapon selection range band, mass fire indicator, and FORCEM assigned priority may be found in Tables 8 through 13, pages 49 to 54.

3. Battalion to Target Range

The ranges from battalions to targets, corresponding to $RANGE_{ij}$ as defined in the optimization model, were obtained from the FORCEM run, but for brevity are not included here. It should be noted that of the 82 targets on the preliminary target list only seven of those targets were within range of cannon and rocket artillery. The other 75 targets were only within range of surface-to-surface missiles. Only targets within range of cannon and rocket artillery will be processed by the optimization model.

B. CURRENT FORCEM METHODOLOGY

1. Engagements

The engagements that resulted from the current FORCEM methodology are shown in Table 4 on page 33. The first column indicates the target number of the engaged target. Suffixes have been added to indicate the target type, MD for maneuver division, SS for support command, and SC for supply convoy. The second column indicates the engaging battalion. If more than one battalion is listed for a target, that target was massed on by the battalions listed. The third column lists the total number of rounds fired by the battalion. The final column lists the FORCEM established priority for this target.

Table 4. FORCEM ENGAGEMENTS

Target	Engaging Battalion	Rounds Fired	FORCEM Priority
MD102016	M102	288	20
	M112	288	
	M122	288	
MD102021	H101	432	19
MD102014	H101	432	19
SS132016	M102	324	7
SS132014	H101	216	7
SC132016	M102	648	2
SC132014	H101	216	2

2. Analysis of Engagement Results

The engagements selected by FORCEM are consistent with the user input values. Based on the experience of the author, the volume of fires against the maneuver divisions seems relatively small considering the number of units represented by a division as well as the 12 hour time step represented. The number of rounds employed against the support commands also seem low, but not to the extent of the maneuver division targets. The number of rounds employed against supply convoys seems reasonable.

C. OPTIMIZATION MODEL METHODOLOGY

1. Optimization Model Specific Data

This section provides the source of data needed for implementation of the optimization model. $TOETUBES_{it}$, $CURTUBES_{it}$, $RANGE_{ij}$, $MAXR_{im}$, $MINR_{im}$, and *TIMESTEP* have been discussed previously. The data required for these are available directly in the FORCEM run.

a. *Ammunition Available (AMMOAVAIL)*

The total amount of ammunition available in each battalion is seen in Table 7 on page 46. Since FORCEM does not currently maintain a specific count of ammunition type by round, one must be developed from the total number of rounds on hand in the battalion. Professional judgment leads to the development of the following estimates for the percentage of HE, ICM and RAP that might be on hand in a battalion. High explosive munition (HE) will compose 25 to 35 percent of the available ammuni-

tion stocks. Improved conventional munition (ICM) will compose 55 to 65 percent of the available ammunition stocks. Finally, rocket assisted projectiles will compose five to 15 percent of the available ammunition stocks.

Since it is unlikely that every battalion has the same distribution of ammunition on hand, random numbers were used with the estimates above to vary the actual number of rounds of each type on hand in the battalions. Results of this effort may be seen in Table 14 on page 53. The data in this table are used in the optimization model for $AMMOAVAIL_{im}$.

b. Current Value of a Target (VALUE)

The current value of a target is critical for the optimization model. The target types used in FORCEM vary greatly in terms of size and importance to the CAC doing the targeting. Targets range from a maneuver division, which is a very large, complex and important target, to a supply convoy, which is a very simple, small and much less important target. In practice artillery battalions do not fire at divisions; they fire at some sub-element of the division such as a company, battery, or troop. This fact is central to the method used in this model to assign current values ($VALUE_j$) to FORCEM targets. The assumption of targeting sub-elements is not unreasonable if we consider that we are trying to compute the number of volleys fired at a large target over a significant period of time, 12 hours. The total engagement over the 12 hours of the time step will be composed of a large number of smaller engagements targeted at specific sub-elements of the larger target.

Each target type in FORCEM is assumed to have a structure as described in *Organization and Equipment of the Soviet Army* [Ref. 6]. This assumed structure is shown in Table 15 on page 54. The first column of the table indicates the FORCEM target type, the second lists target sub-element types of company, battery, or troop size assumed to be in the structure, and the third column lists the quantity of the sub-elements of each type present.

The United States Army Training and Doctrine Command's (TRADOC) System Information Manager's Office for the Advanced Field Artillery Tactical Data System (AFATDS) has developed target quality points for use in prioritizing fire for AFATDS [Ref. 7], which is the next generation command and control computer system for the United States field artillery. These target quality points represent reasonable values for the target sub-elements targeted by battalions since at some point in the near future they will be the values actually used to make engagement decisions. The value assigned to each target sub-element is listed in the fourth column of Table 15 on page

54. Table 5 lists the total number of target sub-elements in each target as well as the total value of the FORCEM target.

Table 5. TARGET SUB-ELEMENTS AND VALUES

Target Type	Target Sub-elements	Target Value
Command and Control Units	4	100
Maneuver Divisions	170	22367
Artillery Battalions	5	525
Communications Units	5	80
Support Commands	27	1200
Supply Convoys	3	28

c. *Effectiveness of a Volley (EFF)*

To preserve the unclassified nature of this thesis JMEM-SS values are not used. In his thesis *A Model For Optimizing Field Artillery Fire*, John A. Marin developed unclassified effectiveness values for a platoon volley fired against various target types [Ref. 8: pp. 34-35]. Effectiveness values derived from this source will be used in lieu of JMEM-SS effectiveness values. The unclassified values were generated using the interactive, two-sided, closed, stochastic, ground combat simulation called Janus(T). Sufficient replications were performed to insure a level of significance of 0.2 ± 0.05 on the value of the effects. The values required for this thesis were extracted and may be found in Table 16 on page 55.

Marin's values must be modified in order to be used effectively in this model. An issue is; how much more effective is a battalion volley than a platoon volley? Marin asserts that a battery mass of two platoons volleys is 1.5 times as effective as a single platoon volley [Ref. 8: p. 35]. This value seems reasonable but raises the question; how much more effective is a battalion mass of three battery volleys than a single battery volley? Current doctrine calls for artillery battalions to be composed of three firing batteries, each having two firing platoons. This structure is assumed for this model. In a tactical situation it is unlikely that all six platoons of a battalion are capable of providing fire support at the same time. Generally a battery may have one platoon in position while the other conducts other essential combat operations. If each battery in the battalion does this, the number of platoons firing in a battalion volley may be as few as

three. In a fluid tactical situation this is the most likely situation. Assuming this to be true, a battalion volley is likely to be only twice as effective as a single platoon volley.

The EFF_{imj} values are computed by multiplying Marin's platoon effects values for the appropriate ammunition and target times two and dividing by the number of sub-elements as listed in column 3 of Table 5 on page 35. The final values ($VALUE_j$) may be found in Table 17 on page 56.

d. Minimum Effects Desired (MINEFF)

The minimum effects desired before allowing an engagement represents data not present in the current FORCEM methodology. While these data are useful for this formulation, they are not required. In order to facilitate comparison of the two methods, an entry of zero will be made for all $MINEFF_j$.

e. Maximum Effects Desired (MAXEFF)

The maximum effects desired when engaging a target represents data not present in the current FORCEM methodology. These data are required for this formulation. As described in Chapter IV a reasonable value is 30 percent. This value will be used for all $MAXEFF_j$.

f. Battalion Time Available (AVAIL)

The time a battalion is expected to be available to fire missions represents data not present in the current FORCEM methodology. These data are critical for this formulation since they seek to replace the previously user-defined maximum number of engagements per time cycle. As previously described, a common tactical approach used by field artillery battalions composed of three batteries of two platoons each is to insure that one platoon of each battery is in position at all times. This frees the other platoon to conduct other combat essential tasks, such as survivability moves, resupply, and repositioning to facilitate support. If this approach is used, the battalion as a whole is generally never in position at the same time. By the same token one-half of the battalion, at least, is always in position. A reasonable estimate of the percentage of time a battalion is in position is 0.5. This value will be used for all $AVAIL_t$ as defined in the optimization model.

g. Time to Fire One Volley (TIME)

The worst case scenario for determining the time required to fire one volley is to assume that each engagement involves only one volley. If this is the case then the time to fire one volley includes processing time at the acquiring asset, the processing time at the CORPS or Brigade tactical operations center, processing time at the battalion fire direction center, processing time at the platoon fire direction center, and lay, load

and firing time at the howitzer. An estimate of this time is 20 seconds at each command level, based on professional judgment. At the howitzer level different ammunition types require different actions. For example, ICM always requires a time fuze which must be manually set. In general ICM and RAP rounds require longer to prepare for firing than do HE rounds. The time required to prepare and fire an HE round will be assumed to be 20 seconds, and ICM and RAP will be assumed to require 30 seconds. These numbers are again based on the professional judgment of the author. $TIME_{im}$ for HE will be 1.67 minutes, and 1.75 minutes for RAP and ICM. Lacking further information the values will be the same for all i battalions

2. Optimization Model Engagements

The model was programmed with the data specified previously and solved with the General Algebraic Modeling System (GAMS), a product of The International Bank for Reconstruction and Development, the World Bank [Ref. 9]. GAMS was selected because of the familiarity of the author with the package. The GAMS program listing is given in Appendix D. The model could be programmed and run on any number of packages, or an efficient package developed based on its interaction with the rest of the FORCEM model.

The engagements that resulted from the optimization model methodology are shown in Table 6 on page 38. The first column indicates the target number of the engaged target. The second column indicates the battalion(s) that engaged the target. The third column indicates the type of ammunition used in the engagement, and the last column the number of rounds in the engagement.

Table 6. OPTIMIZATION MODEL ENGAGEMENTS

Target	Engaging Battalion	Ammunition Used	Rounds Fired
MD102016	M122	HE	880
	M132	HE	1440
	M142	ICM	748
	M162	HE	1552
	M192	HE	1376
MD102021	H101	HE	950
	M102	RAP	352
	M142	RAP	612
	M152	HE	1456
		ICM	1152
	M162	RAP	304
	M172	HE	1394
	M103	RAP	275
MD102014	M102	HE	1648
		ICM	1408
	M112	HE	1840
	M132	RAP	432
	M152	RAP	288
	M182	RAP	629
SS132016	H101	RAP	527
	M122	HE	448
SS132014	M122	HE	416
	M172	RAP	578
SC132016	H101	RAP	67
SC132014	M132	HE	64

3. Analysis of Engagement Results

As with the FORCEM engagements, all targets within range of cannon artillery were engaged. The bulk of the rounds, as expected, were expended against the three maneuver division targets. The support command targets received significant volumes

of fire and the supply convoys a much smaller volume. In terms of expected outcomes, there were no surprises in the optimization model engagements.

4. Effects of the Constraints

In the linear program the constraints are used to control the outcome of the model. In this case the availability of ammunition and the maximum effects allowed were, in most cases, binding constraints. Because of the relatively small number of targets available, the maximum effects of 30 percent were achieved against all seven targets. The importance of setting an appropriate level of $MAXR_{i,m}$ is shown in this example. A higher value of $MAXR_{i,m}$ would have resulted in all ammunition being expended by all battalions. This variable is as important in determining ammunition consumption as the ammunition level ($AMMOAVAIL_{i,m}$) itself.

Even though a worst case estimate of the time required to fire one volley ($TIME_{i,m}$) was used in the optimization model, the constraint was very loose. The battalion that used the most time used only 368 minutes of the 720 minutes in the time step (less than 52%). The value for this variable is not critical if the ammunition available to a battalion in a time step is of the same or smaller magnitude than that found in this example data set. The criticality of this value could be quickly checked by determining the time required to fire the number of volleys represented by the ammunition on hand in the unit, *i.e.*, total number of rounds ($\sum_m AMMOAVAIL_{i,m}$) divided by the number of tubes on hand ($CURTUBES_i$) times the maximum time required to fire one volley ($TIME_{i,m}$) . If this value is less than the percentage of time the battalion is available ($AVAIL_i$) times the length of the time step, then this constraint will not be binding and could be eliminated from the linear program for the current time step for that battalion. This check could be placed in the preprocessor that develops the equations for the model. Elimination of such constraints would make the optimization more efficient.

D. CONCLUSIONS

1. Comparison of Engagement Results

The engagement results shown for the current methodology (Table 4 on page 33) and the optimization model (Table 6 on page 38) are obviously very different. Consider the target MD102016, the highest priority target in this run. The current methodology engaged the target with three battalions, each firing 288 rounds for a total of 864 rounds of ammunition. Based on the effectiveness values for ICM assumed in the optimization model the effects on this maneuver division would be at most 8.064 percent. The optimization model engaged the target with five battalions firing a total of

5996 rounds of HE and ICM; achieving an effectiveness of 30 percent. The difference is the result of the nature of the instructions given the models. The current methodology requires that the analyst decide, before the simulation, how many rounds should be used in an engagement against a certain target type. The tendency may be to make this estimate conservatively because of the lack of knowledge of conditions when making the decision. For example, if a very large number of rounds is specified for a target, a point could be reached in the model where no targets could be engaged due to a lack of ammunition. The values seen here reflect a conservative approach that results in targets always being engaged, but with less effect than is desired or possible. The optimization model is not tied to a specific size of engagement and will seek to achieve the greatest possible effect in terms of target value. In this case the low number of targets and abundance of ammunition allowed the optimization model to achieve significantly greater effects on the targets than the current methodology.

2. Advantages of the Optimization Model

The optimization model in its current form is simple, easy to understand, and relatively easy to implement. Simplicity is a desired trait because of the number of times the model may be invoked during a normal run of FORCEM. FORCEM simulations normally cover a period of 60 to 90, with up to 180 time steps. If the blue side has 20 CORPS involved in the simulation the optimization model would be called 3600 times for one run.

The requirement for the analyst to input the prioritized lists of weapons and number of rounds with which to engage targets is eliminated. Eliminating this requirement reduces the effect of the judgment of the analyst on the outcome of the model.

Target values are dynamically determined, eliminating the requirement for the analyst to input an ordinal priority list of all possible targets. This also allows the relative importance of targets, as reflected in their values, to change over time.

The assignment of missions to battalions does not depend on the order that the battalions are listed in the input. All battalions are considered for each engagement by the model, not one at a time, as in the current methodology.

Ammunition used in the fire support process is accounted for by type, insuring that only available ammunition is used. This provides a more accurate representation of the effects of artillery as well as a more realistic testing of the logistics system.

The optimization model provides a framework that could be embellished very easily. Additional ammunition types could be explored simply by adding an index and

supporting effects data. Such a change could be examined without requiring decisions by the analyst that could influence the results of the study.

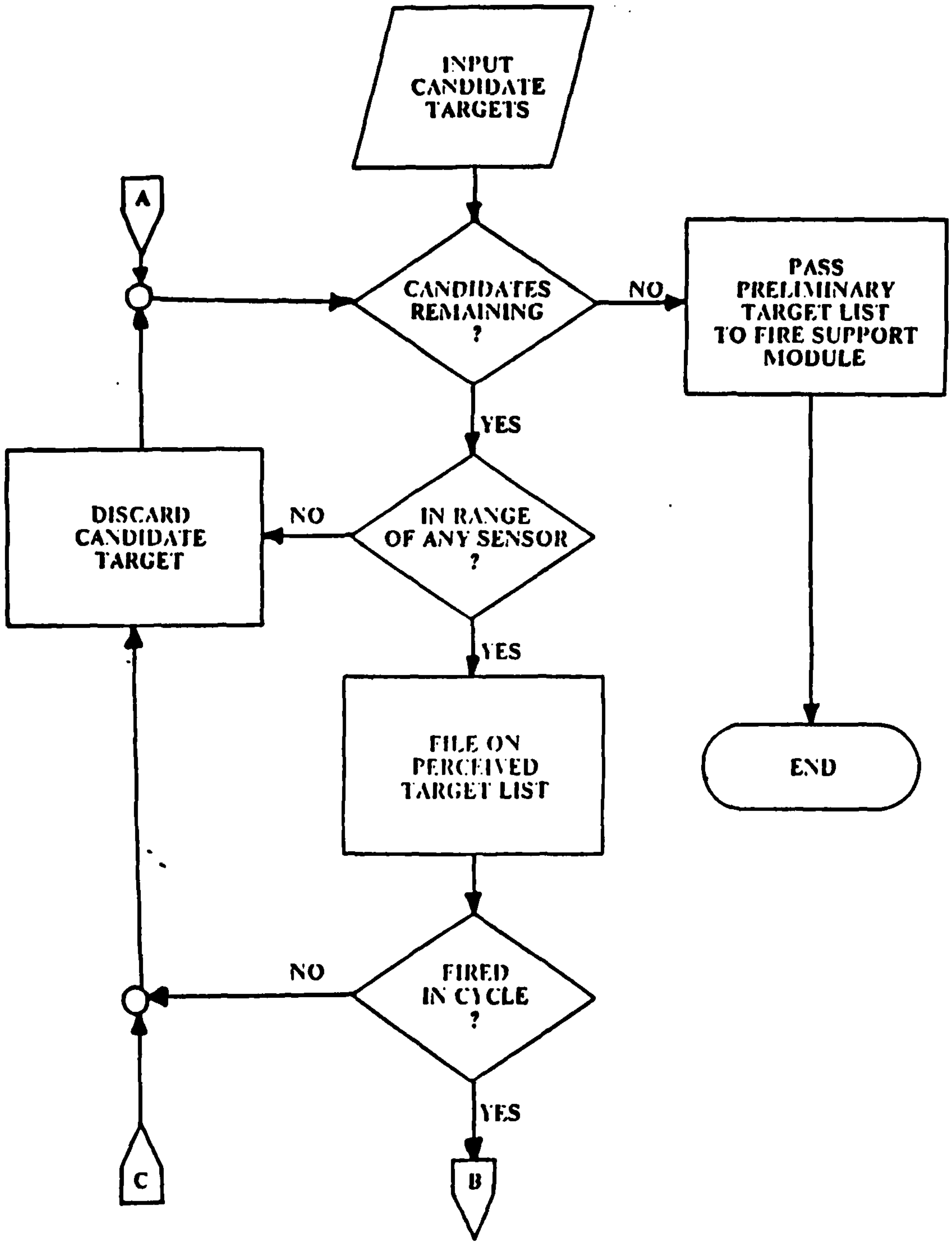
3. Disadvantages of the Optimization Model

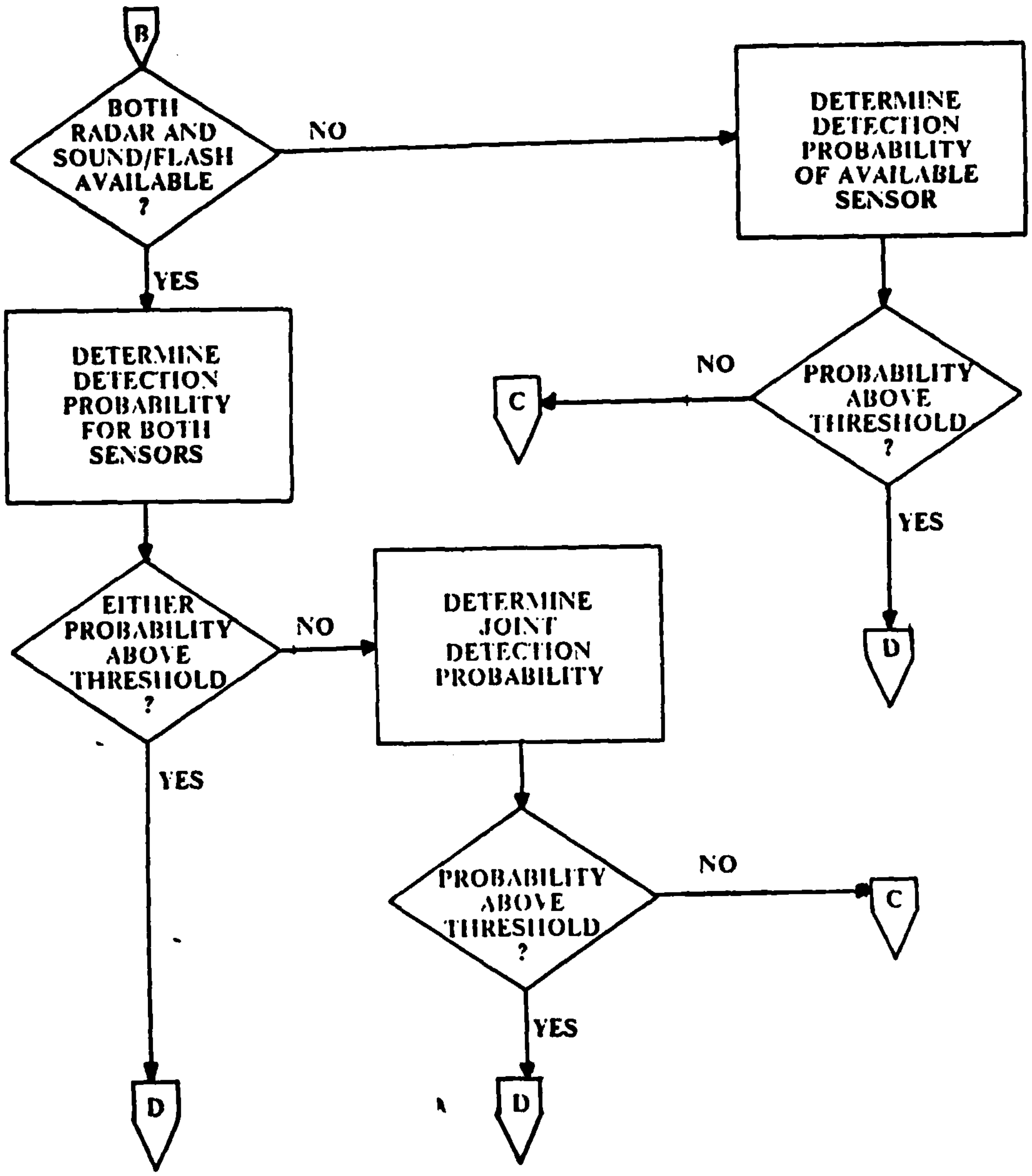
The principle disadvantage of the model is the requirement for additional data. Although some previously required data are eliminated, additional data are required to implement the model. This thesis demonstrates that the required data are available. Further, the new data required will not change routinely unless such a change is the goal of the study. The generation of target values could easily be automated, using the TOE structures already available in FORCEM. Implementation of ammunition by type will require changes to the logistics sub-module of FORCEM.

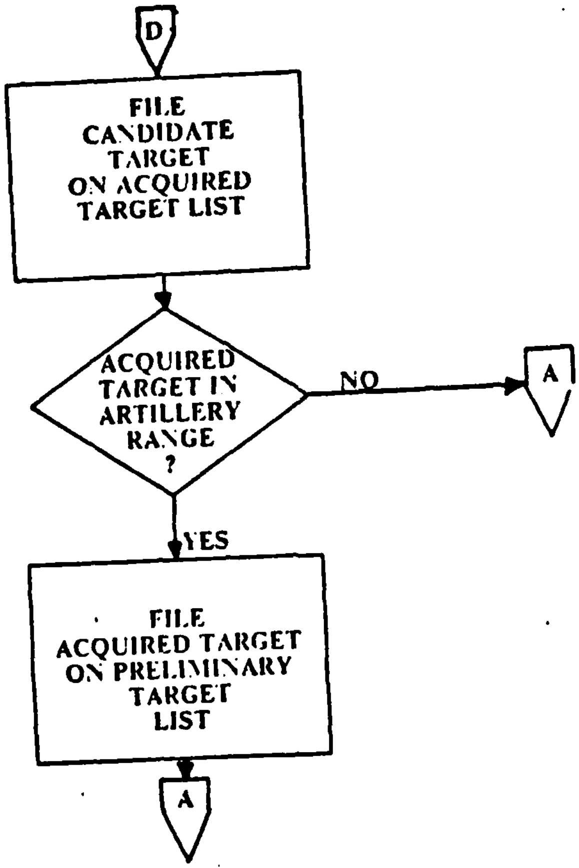
4. Recommendation

CAA should implement an optimization model such as the one described in this thesis for use in allocating blue fire support in the FORCEM model. The advantages of such a model outweigh the disadvantages significantly. Such a model will improve the capabilities of FORCEM to accurately portray combat at the theater level.

APPENDIX A. ACQUISITION DETERMINATION FLOW CHART




B
BOTH RADAR AND SOUND/FLASH AVAILABLE ?
NO
YES
DETERMINE DETECTION PROBABILITY OF AVAILABLE SENSOR
DETERMINE DETECTION PROBABILITY FOR BOTH SENSORS
PROBABILITY ABOVE THRESHOLD ?
NO
C
YES
D
EITHER PROBABILITY ABOVE THRESHOLD ?
NO
DETERMINE JOINT DETECTION PROBABILITY
YES
PROBABILITY ABOVE THRESHOLD ?
NO
C
YES
D
D


D
FILE CANDIDATE TARGET ON ACQUIRED TARGET LIST
ACQUIRED TARGET IN ARTILLERY RANGE ?
NO
A
YES
FILE ACQUIRED TARGET ON PRELIMINARY TARGET LIST
A

APPENDIX B. FORCEM RUN DATA

A. FIRING BATTALION DATA

The list of available firing battalions is shown in Table 7 on page 46. The columns of the table provide information about the firing battalions that are currently available in FORCEM. Firing battalions are considered available in FORCEM if they have sufficient tube and personnel strength remaining. Critical values for these data are user input.

The column labeled Battalion lists a unique battalion name for each battalion available. For ease in reference, each battalion name has a suffix with the following meaning:

M	Medium Field Artillery Battalion (M109A3 155mm)
H	Heavy Field Artillery Battalion (M110A2 203mm)

The column labeled Tube Strength contains two numbers. The first number is number of tubes authorized by the Table of Organization and Equipment (TOE), corresponding to $TOETUBES_i$ as defined in the optimization model. The second number is the number of tubes on hand at the start of the time step, corresponding to $CURTUBES_i$ as defined in the optimization model.

The column labeled Ammunition Available gives the total number of rounds of ammunition available (on hand) in the battalion at the beginning of the time step. These data will be used to develop $AMMOAVAIL_{im}$ as defined in the optimization model.

Table 7. FIRING BATTALION LIST

Battalion	Tube Strength TOE OH	Total Ammunition On Hand
H101	18 10	4002
M102	18 16	4694
M112	18 16	4694
M122	18 16	4694
M132	18 16	4694
M142	18 17	4694
M152	18 16	4694
M162	18 16	4694
M172	18 16	4694
M182	18 17	4694
M192	18 16	4694
M103	18 11	4694

B. PRELIMINARY TARGET DATA

The preliminary target list is shown in the following six tables. Each table lists a specific target type. The columns of the tables provide information about the targets available in FORCEM.

The Target column lists a unique target number for each target on the preliminary target list. For ease of reference, each target number has a suffix with the following meaning:

CC Command and Control Headquarters
MD Maneuver Division
FA Field Artillery Battalions
CU Communications Units
SS Support Commands
SC Supply Convoys

The entries in the Range Band column are used in FORCEM for the selection of cannon and rocket artillery or surface-to-surface missiles with which to engage the target. The range bands used for this run are shown below:

1	0 to 10,000 meters from the CAC
2	10,001 to 30,000 meters from the CAC
3	30,001 to 200,000 meters from the CAC
4	more than 200,001 meters from the CAC

Targets in range bands 1 and 2 can be engaged by cannon or rocket artillery fire. Targets in range band 3 can only be engaged by surface-to-surface missiles. Targets in range band 4 are not within range of surface-to-surface assets available to the CAC.

The mission of this target's command and control headquarters (CAC), listed in the third column, may be one of the following:

1. Attack
2. Defend
3. Delay
4. Withdraw

The mass fire target indicator, column four, will have an entry of Yes or No. A Yes indicates that FORCEM will seek to fire multiple battalions against this target, called massing on the target. A No indicates that FORCEM will not mass on this target.

The final column lists FORCEM priority, an integer used by FORCEM to prioritize the targets; the larger the number, the more important the target.

Table 8. COMMAND AND CONTROL HEADQUARTERS PRELIMINARY TARGETS

Target	Range Band	CAC Mission	Mass Fire Target	FORCEM Priority
CC102020	3	Attack	No	12
CC102010	3	Attack	No	12

Table 9. MANEUVER DIVISION PRELIMINARY TARGETS

Target	Range Band	CAC Mission	Mass Fire Target	FORCEM Priority
MD102022	3	Attack	Yes	28
MD102013	3	Attack	Yes	28
MD102016	1	Attack	Yes	20
MD102021	2	Attack	Yes	19
MD102014	2	Attack	Yes	19
MD102032	3	Attack	Yes	14
MD102031	3	Attack	Yes	14
MD102051	3	Attack	Yes	14
MD102053	3	Attack	Yes	14
MD102033	3	Attack	Yes	14
MD102015	3	Attack	Yes	14
MD102012	3	Attack	Yes	14
MD102024	3	Attack	Yes	14
MD102023	3	Attack	Yes	14
MD102011	3	Attack	Yes	14

Table 10. FIELD ARTILLERY BATTALION PRELIMINARY TARGETS

Target	Range Band	CAC Mission	Mass Fire Target	FORCEM Priority
FA112023	3	Attack	No	26
FA112025	3	Attack	No	26
FA112022	3	Attack	No	26
FA112024	3	Attack	No	26
FA112026	3	Attack	No	26
FA112027	3	Attack	No	26
FA112127	3	Attack	No	26
FA112227	3	Attack	No	26
FA112327	3	Attack	No	26
FA112427	3	Attack	No	26
FA112015	3	Attack	No	26
FA112021	3	Attack	No	13
FA112527	3	Attack	No	13
FA112028	3	Attack	No	13
FA112011	3	Attack	No	13
FA112012	3	Attack	No	13
FA112013	3	Attack	No	13
FA112014	3	Attack	No	13

Table 11. COMMUNICATIONS UNIT PRELIMINARY TARGETS

Target	Range Band	CAC Mission	Mass Fire Target	FORCEM Priority
CU162016	2	Attack	No	3
CU162014	2	Attack	No	3
CU162032	3	Attack	No	2
CU162031	3	Attack	No	2
CU162020	3	Attack	No	2
CU162051	3	Attack	No	2
CU162053	3	Attack	No	2
CU162010	3	Attack	No	2
CU162033	3	Attack	No	2
CU162015	3	Attack	No	2
CU162012	3	Attack	No	2
CU162011	3	Attack	No	2
CU162022	3	Attack	No	2
CU162021	3	Attack	No	2
CU162024	3	Attack	No	2
CU162023	3	Attack	No	2
CU162013	3	Attack	No	2

Table 12. SUPPORT COMMAND PRELIMINARY TARGETS

Target	Range Band	CAC Mission	Mass Fire Target	FORCEM Priority
SS132016	2	Attack	No	7
SS132014	2	Attack	No	7
SS132032	3	Attack	No	6
SS132031	3	Attack	No	6
SS132020	3	Attack	No	6
SS132051	3	Attack	No	6
SS132053	3	Attack	No	6
SS132010	3	Attack	No	6
SS132033	3	Attack	No	6
SS132015	3	Attack	No	6
SS132012	3	Attack	No	6
SS132011	3	Attack	No	6
SS132022	3	Attack	No	6
SS132021	3	Attack	No	6
SS132024	3	Attack	No	6
SS132023	3	Attack	No	6
SS132013	3	Attack	No	6

Table 13. SUPPLY CONVOY PRELIMINARY TARGETS

Target	Range Band	CAC Mission	Mass Fire Target	FORCEM Priority
SC131043	3	Attack	No	2
SC131042	3	Attack	No	2
SC131041	3	Attack	No	2
SC132023	3	Attack	No	2
SC132021	3	Attack	No	2
SC132022	3	Attack	No	2
SC132024	3	Attack	No	2
SC132014	3	Attack	No	2
SC132015	3	Attack	No	2
SC132013	3	Attack	No	2
SC132011	3	Attack	No	2
SC132016	2	Attack	No	2
SC132012	2	Attack	No	2

APPENDIX C. OPTIMIZATION MODEL DATA

A. FIRING BATTALION DATA

Table 14 lists the number of rounds of ammunition available in the battalion at the beginning of the time step. These data were generated from the FORCEM total ammunition on hand quantity found in Table 7 on page 46. The method of generation is described in Chapter V. These data correspond to $AMMOAVAIL_{im}$ as defined in the optimization model.

Table 14. AMMUNITION AVAILABLE

Battalion	HE On Hand	ICM On Hand	RAP On Hand
H101	954	2453	595
M102	1650	2677	367
M112	1851	2605	238
M122	1767	2636	291
M132	1510	2743	441
M142	1309	2772	613
M152	1466	2930	298
M162	1552	2825	317
M172	1316	2824	554
M182	1160	2899	635
M192	1391	2946	357
M103	1679	2737	278

B. TARGET VALUES

Table 15 on page 54 reflects the development of the current value of a target ($VALUE_j$) as defined in the optimization model. The first column is the FORCEM target type. The second column lists target sub-element types of the FORCEM target. An entry of **TOTAL** in this column indicates that the row contains the column sums for columns three and five for targets having multiple sub-elements. Targets with no entry in the Target Sub-element column are assumed to be homogeneous in type, all target sub-elements are essentially identical and need not be differentiated. Column three lists

the quantity of sub-elements in the target. Column four lists the value of one target sub-element. Column five lists the total value of the target sub-elements for non-homogeneous targets, and the total value of the target for homogeneous targets. The total value for non-homogeneous targets is listed in the row labeled **TOTAL** for the target type.

Table 15. TARGET VALUES

Target	Target Sub-element	Quantity	Value	Total Value
Command and Control Units		4	25	100
Maneuver Divisions	Division HQ	1	95	95
	Regimental HQ	6	90	540
	Battalion HQ	32	85	2720
	Medium Artillery	18	135	2430
	Rocket Artillery	6	161	9660
	Mech Infantry	34	80	2720
	Armor	18	88	1584
	Air Defense	9	72	648
	Target Acquisition	1	80	80
	Support	54	35	1890
	TOTAL	179		22367
Artillery Battalions	Battalion HQ	1	85	85
	Medium Artillery	3	135	405
	Support	1	35	35
	TOTAL	5		525
Communications Units		5	16	80
Support Commands	Brigade HQ	1	90	90
	Battalion HQ	4	85	340
	Support	22	35	770
	TOTAL	27		1200
Supply Convoys		3	9	27

C. EFFECTIVENESS DATA

Table 16 lists effectiveness values of one platoon volley of the ammunition type listed in the column heading against a company, battery, or troop size sub-element of a target of the type listed as the row heading.

Table 16. EFFECTS OF ONE PLATOON VOLLEY AGAINST TARGET SUB-ELEMENTS

Target Type	Ammunition Type			
	HE	RAP	ICM1	ICM2
Command and Control Units	0.06	0.05	0.15	0.11
Maneuver Divisions	0.07	0.06	0.15	0.11
Artillery Battalions	0.03	0.03	0.13	0.09
Communications Units	0.06	0.05	0.15	0.11
Support Commands	0.08	0.07	0.12	0.11
Supply Convoys	0.12	0.12	0.24	0.20

Table 17 on page 56 lists effectiveness values, EFF_{imjt}, for all battalions i as defined in the optimization model.

Table 17. EFFECTS OF ONE BATTALION VOLLEY (EFF)

Target Type	Ammunition Type			
	HE	RAP	ICM1	ICM2
Command and Control Units	0.03000	0.02500	0.07500	0.05500
Maneuver Divisions	0.00078	0.00067	0.00168	0.00123
Artillery Battalions	0.01200	0.01200	0.05200	0.03600
Communications Units	0.02400	0.02400	0.06000	0.04400
Support Commands	0.00593	0.00519	0.00889	0.00815
Supply Convoys	0.08000	0.08000	0.16000	0.13333

APPENDIX D. GAMS PROGRAM LISTING

```
SETS
   I    index set of delivery units (battalions)

   J    index set of targets

   M    index set of munition types

PARAMETERS
   VALUE(J)  estimated current value of target j

   MINEFF(J)  minimum effects desired to engage target j

   MAXEFF(J)  maximum effects desired when engaging target j

   CURTUBES(I)  rounds in a battalion volley from unit i

   TOETUBES(I) tubes assigned to unit i

   AVAIL(I)  percentage of time unit i is available;


TABLE
   OHAMMO(I,M)  rounds of munition m on hand at delivery unit i;

TABLE
   RANGE(I,J) the range (decameters) from delivery unit i to target j;

TABLE
   MAXR(I,M) the maximum range of unit i firing munition (decameters);

TABLE
   MINR(I,M) the MINIMUM range of unit i firing munition (decameters);

TABLE
   EFF(I,M,J) the effectiveness of 1 volley of m fired by i at j (%);

TABLE
   TIME(I,M) the time required to fire 1 volley of m from i (minutes);

PARAMETER
   ALLOW(I,J,M) determines if unit i can fire at target j using m;
   ALLOW(I,J,M)$(RANGE(I,J) LE MAXR(I,M) AND RANGE(I,J) GE MINR(I,M))=1;

PARAMETER
   PERTUBES(I)  percent tubes available-curtubes divided by toetubes;
   PERTUBES(I) = CURTUBES(I)/TOETUBES(I);

SCALAR
   TIMESTEP minutes in a time step;
```

```
VARIABLE
   TOTVAL the total target value killed;

POSITIVE VARIABLES
   VOLLEY(I,J,M) number of battery volleys of m fired by i at j;

   ALLOC(I,M) allocation of icm to range band use;

EQUATIONS
   OBJ objective function - maximize the total target value killed;

   EFFUPPER(J)  do not exceed maximum desired effects for target j;

   EFFLOWER(J)  achieve minimum desired effects on target j;

   HEAMMO(I,M) he ammunition available at unit i is not exceeded;

   RAPAMMO(I,M) rap ammunition available at unit i is not exceeded;

   ICM1ALOC(I,M) allocate icm1 ammunition to range bands;

   ICM2ALOC(I,M) allocate icm2 ammunition to range bands;

   ICMAMMO(I,M) icm ammunition available at unit i is not exceeded;

   TOTTIME(I) time available at unit i is not exceeded;

* maximize

   OBJ..
   TOTVAL =E= SUM((J,M,I),
   (VOLLEY(I,J,M)*EFF(I,M,J)*ALLOW(I,J,M)*PERTUBES(I)*VALUE(J)));


* subject to

  HEAMMO(I,'HE')..
  SUM(J,(VOLLEY(I,J,'HE')*CURTUBES(I)*ALLOW(I,J,'HE')))
  =L= OHAMMO(I,'HE');

  RAPAMMO(I,'RAP')..
  SUM(J,(VOLLEY(I,J,'RAP')*CURTUBES(I)*ALLOW(I,J,'RAP')))
  =L= OHAMMO(I,'RAP');

  ICM1ALOC(I,'ICM1')..
  SUM(J,(VOLLEY(I,J,'ICM1')*CURTUBES(I)*ALLOW(I,J,'ICM1')))
  =L= ALLOC(I,'ICM1');

  ICM2ALOC(I,'ICM2')..
  SUM(J,(VOLLEY(I,J,'ICM2')*CURTUBES(I)*ALLOW(I,J,'ICM2')))
  =L= ALLOC(I,'ICM2');

  ICMAMMO(I,'ICM')..
  SUM(J,
  ALLOC(I,'ICM1')*ALLOW(I,J,'ICM1')+ALLOC(I,'ICM2')*ALLOW(I,J,'ICM2'))
  =L= OHAMMO(I,'ICM');
```

```
  TOTTIME(I)..
  SUM(M,(TIME(I,M)*(SUM(J,ALLOW(I,J,M)*VOLLEY(I,J,M)))))
  =L= (AVAIL(I)*TIMESTEP);

  EFFUPPER(J)..
  SUM((M,I),(VOLLEY(I,J,M)*ALLOW(I,J,M)*EFF(I,M,J)*PERTUBES(I)));
  =L= MAXEFF(J)

  EFFLOWER(J)..
  SUM((M,I),(VOLLEY(I,J,M)*ALLOW(I,J,M)*EFF(I,M,J)*PERTUBES(I)));
  =G= MINEFF(J)

MODEL ALLOCATE/ALL/; SOLVE ALLOCATE MAXIMIZING TOTVAL USING LP;
```

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